Systems Engineering
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Lecture - 23
Design Synthesis

Good morning. Welcome to the 23rd lecture of systems engineering on Design Synthesis. And today we are going to talk about the third step in the Systems engineering process.

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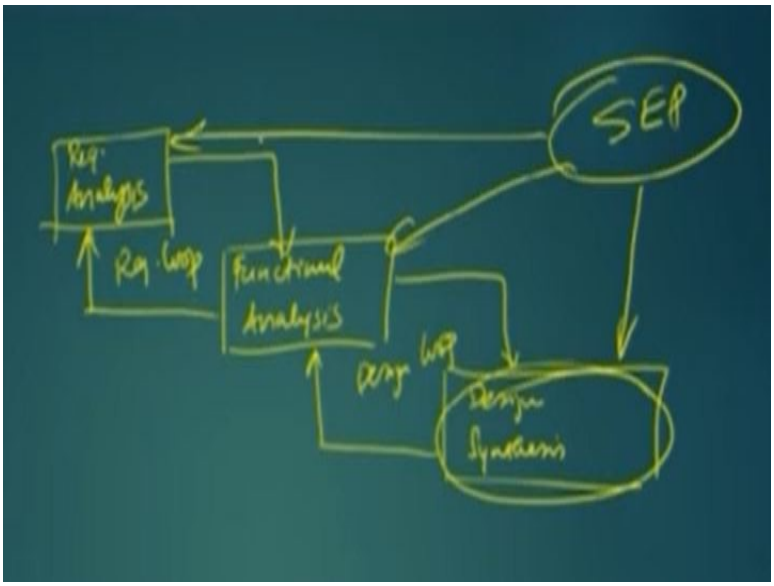

Earlier we have talked about the Requirement analysis, then we talked about Functional analysis, now we are talking about the third step which is the Design Synthesis. So and we had that Requirement loop and we had the Design loop. This is kind of the globally accepted model that we talked about in many places discussing on. That's how we are now going to focus on the third aspect and what is the systems engineering, and we remember we seeing that systems engineering process being there controlling all the three aspects.

So in this case, we are actually looking at the third stage the Design synthesis and how systems engineering process gets applied to Design synthesis.

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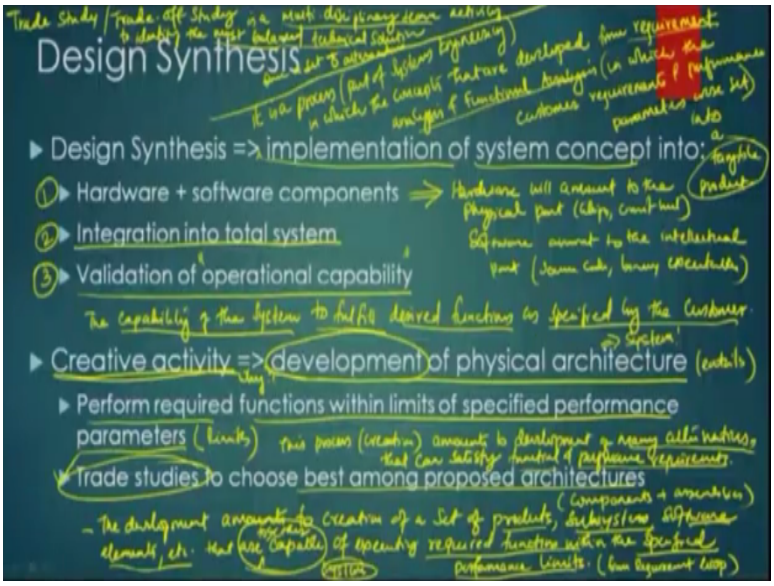

So the first and foremost thing in the designs synthesis is the implementation of a systems concept into a hardware and software components and then the integration to the total system and validation of the operational capability. So if we write about this then we can say that design synthesis, it is a process part of systems engineering.

It is a process, that's a part of the systems engineering in which the concepts that are developed, when were this concept developed or the system concept when was this developed? These concepts that are developed from Requirement analysis and Functional analysis, so both of these analysis. So the system concepts were developed from these functional and system analysis, in which the customer requirements and performance parameters were set.

So, Design synthesis is a process in which the concept that are developed from requirement analysis and functional analysis. In that we were actually developing the customer requirements and performance parameters into a tangible product. So how is this tangible product? When you are trying to implement the system concept that are developed as part of requirement and functional analysis into a tangible product, into a final product.

So then what are the aspects that we need to do? So in a way, it requires what you call as hardware and software components, so you can think about it as hardware will amount to the physical part like chips, circuit board etc. Software amount to the intellectual part which is the

source code, binary executable etc. So the hardware and the software components both are developed as the part of the system synthesis or design synthesis.

And then this hardware and software things are Integrated into a total system. So a complete system is developed by integrating them and once the integration happened, then the operational capability of the system, this implies the capability of the system to fulfill desired functions as specified by the customer. So we have to ensure that the system has operational capability which means is a capability of the system to fulfill or to satisfy the desired functions.

Those functions, who specified those functions? They are specified by the customer. So these 3 things the hardware and software components developing them, then integrating them into a total system then validating that the integrated system has the necessary operational capability is in a way, can say design synthesis in a nut shell but also please remember that Design synthesis is a creative activity. So the creative activity, it is called a creative activity, why is it a creative activity? Because it involves, it entails the development of the physical architecture.

It entails or results in the development of the physical architecture or physical architecture you can think about it as the physical system. So that is the reason it is called as a creative activity. So, what is the development process? The development amounts to what? Amounts to creation of a set of what? Products, subsystems, software elements etc. that are capable of executing, that are together capable of executing required functions within the specified performance limits.

So what we are saying is this development it is not just make any system, this development in particular is amounts to the creation of a set of products, sub systems, software elements etc. so, in a way you can think about all of these are components + assemblies. All of these that they are together capable, so when you integrate all of them into a system then it is capable of executing the required functions whichever the functions that are required, who required these functions?

The customer required these functions. Required functions within the specified performance limits. So their performance limits, these were specified, when were such specified, from requirement loop. So all those things that were specified in the requirement loop are actually

taken and then from that requirements you develop components, products, sub systems, software elements etc. and then integrate them together into form the system that is capable of executing those functions.

So that's what we said perform required functions within specified performance parameters or within specified performance limits. So the one trick is that many a times you know, usually there are many hardware or software things, so, this process is the creation process amounts to development of many alternatives. So when you have many alternatives that can satisfy the functional and performance requirements.

So you will end up many system design or many alternatives, which can do the same thing functional and performance requirements then you need to do trade studies. So the creative activity or the design synthesis also includes the trade study to choose the best among the proposed architecture. So there was a question by students, some students want what is a Trade study? So I thought I will explain what is a trade study?

Trade study is also known as study or what we call as trade off study is a multidisciplinary team activity, what happens in this multidisciplinary activity? To identify the most balanced technical solution from a set of alternatives. So you have a set of alternatives from which you try to find out the most balanced Technical solution and it is also a multidisciplinary team activity. Remember in this process we have already mentioned why multidisciplinary teams are quite important in development in Systems engineering.

So I said an example in the UAV when we were trying to look at the propulsion system, we had people from mechanical engineering who were working in the area of engines, IC engines, we have people from the electrical engineering who were working in the area of brushless DC motors, we had people in the, people who actually working in the engine control systems, fuel management, there are people who are working in the propeller design.

So all these teams put together there, some people gave the idea of the propellers, some gave the idea of the prime mover, there were two fuel based and electric and some people gave the idea of

engine control etc. So all these things put together we were able to identify what would be the, what is the ideal combination of propeller press. So if you are using a brushless DC motor, what is a right propeller choice?

And we are using gasoline engine, which is a right propeller choice? And what is the right engine management system for a DC motor? What is a right engine and fuel management system for a IC engine? These things, these decisions were typically taken as part of the multidisciplinary team because there were many alternatives available and we were doing trade off studies in this regard. So now we will go to what is called as Design synthesis process.

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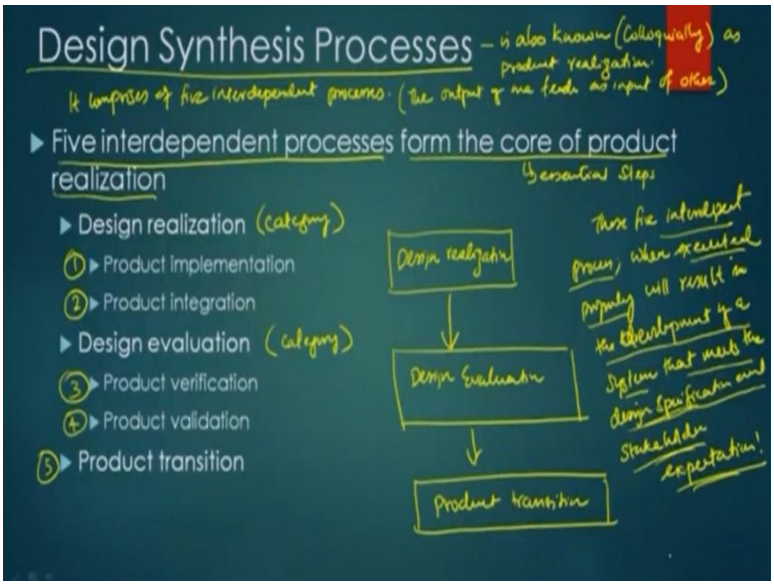

So this process is also known, this is also known in a sense it is colloquially known. People use this in that particular you know, a colloquial fashion is known as, it is known as what? It is known as the product realization. So many a people call this as a product realization step or some people call this as a product realization. But the correct term for it is the Design synthesis process and this whole process, it comprises of five interdependent processes.

They are interdependent because the output of one feeds as input of other. So you can understand that the output from one process actually becomes the input to other process. So these are these five interdependent processes. So which are those five interdependent processes? Because these processes they form the core of the product realization or they are the essential steps to realize a

product.

So the first one is called the Design realization. This is a category in which you have to the first one is product implementation second one is product integration. Then the second category is design evaluation. Within which the third one is the product verification and the fourth one is product validation. Finally, the fifth one is the product transition. So the thing what we talk about it is, in this area if you draw this diagrammatically it can kind of thing, you can think like this.

Let us say Design realization from there we do Design evaluation from there we do Product transition. In a simplistic sense, we can actually draw the diagram in this fashion. So the aim is that, these five interdependent process, when executed properly will result in the development of a system that meets the design specification and stakeholder expectation. So what we are saying is these five interdependent processes, if they are executed properly it will result in the development of a system that meets the design specification and stakeholder expectation.

So the aim is to actually run through this processes, so that you end up developing a system that actually needs the design specs and stakeholder expectation. So there are many things that are part of this design synthesis process. So let's actually look at a schematic in which with all the sub processes in this.

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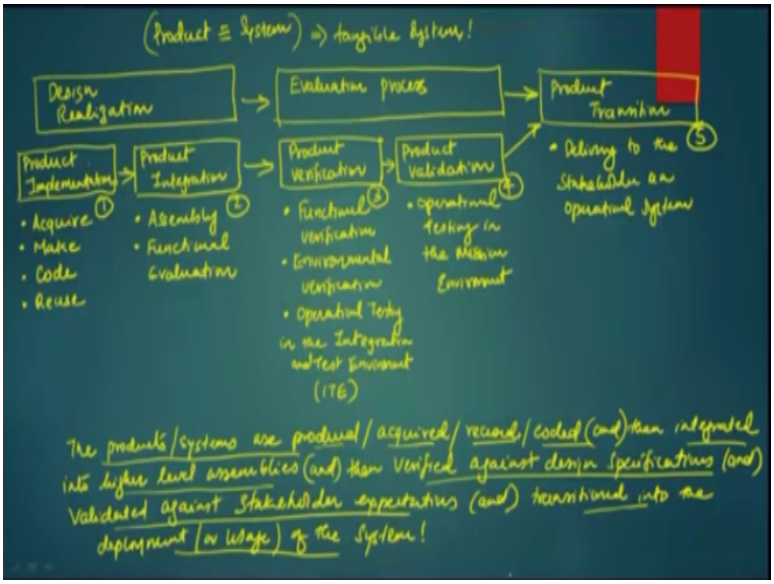

So if you look at it, I will kind of draw this in a horizontal fashion. So we will draw the first part, which is the Design realization, then we will draw the second part, which is the Evaluation process, then we will draw the third one, which is the Product transition. So we draw something like this, so that it starts from Design realization, Evaluation process and Product transition. In this we have two, the first one is the Product Implementation, second one is the Product Integration, then we do what we call as, there is two again here as mentioned Product verification then the other one is Product validation and then the final one is the Product transition.

So what happens in the Product implementation, the first thing that the options within this is we can think about acquiring something, we can think about making something, we can think about coding something or we can think about reusing something. So, those are the main product implementation, you are trying to implement the product where acquire, make, code, reuse these are the main activities as part of it.

In the product integration the main part is assembly and functional evaluation. So, you assemble the product and then check for whether it is doing the right functional aspects of the product. Among the product verification, the main things that we do is the functional verification. Second is the environmental verification and the third part is the operational testing. And we will discuss about this operational testing in a minute. And in the product validation, it is basically also operational testing.

Why do we need to do operational testing? This difference is this. In the product verification, the operational testing in the integration and test environment, whereas, this is in testing in the mission environment. So, this happens in the ITE environment, Integration and Testing Environment, where this happens in the mission environment. Then in this case, the last case it is the delivery to the stake holder and operational system. So this is the, and then you can think about it as, each steps feeding into what it is.

So here is our step 1, step 2, step 3, step 4 and step 5. So, step 1 is product implementation, step 2 is product integration, step 3 is product verification, step 4 is product validation and finally product transition. So, here I am using the term product as an equivalent to a system. Remember

we mentioned earlier that we are talking about tangible things only, tangible systems or sometimes products as such. We are not talking about software systems or intangible systems.

So if we write about this, the idea is this, that the products or systems are produced or acquired or reused or coded and then integrated into higher level assemblies and then verified against design specifications and validated against stakeholder expectations and transitioned into the deployment or usage of the system.

So, in a way if you look at that, the simplistic sense is that the aim is to produce systems, produce or acquire or reuse or code such that these can be integrated into the higher level assemblies and then verified against design specifications and validated against stakeholder expectations and transitioned into the final deployment.

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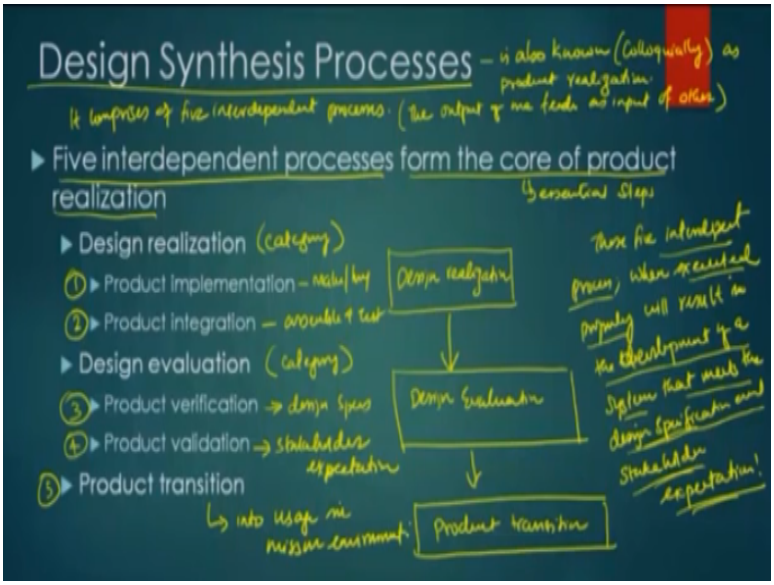

So, if we go back to the previous slide, we can say that the product implementation, this is where the make, buy etc. happens, the integration is the assemble and test. This product verification is against the design specs. This is the stakeholder expectations and finally the product transition is into usage in mission environment.

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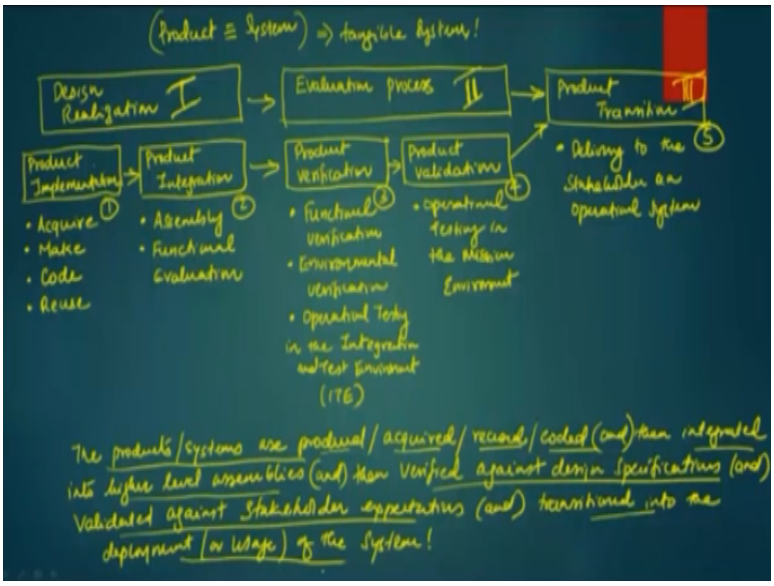

So the same thing we basically wrote it in a nice sentence so that you can actually remember this clearly. So, once we have seen that this is a 5 step process and the 2 steps, the step 1 and 2 together are part of this design realization and so we call it as the main step I, not step I actually it is a subset I or a heading I and then we can call this as heading II, which is the evaluation process and the third one is the product transition.

And the design realization has product implementation and product integration as the 2 steps and evaluation has product verification and product validation as 2 steps and product transition basically is just one step, it is product transition in itself.

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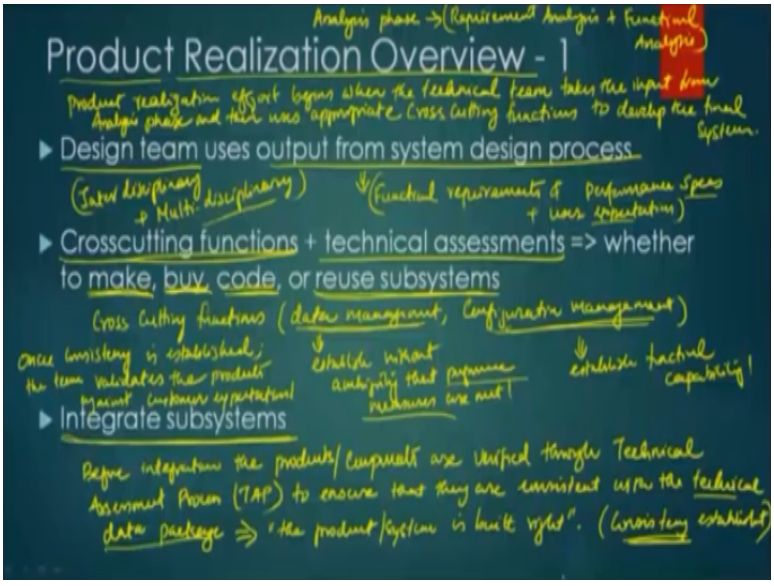

With that what we will try to do is we will try to move into the product realization overview or we will actually look at how the product realization happens. So, if we write about this we can say that product realization effort begins when the technical team, the other name for this technical team is also design team, technical team takes the input from analysis phase. The analysis phase, remember this has 2 parts, the requirement analysis plus functional analysis.

So both of these are part of the analysis phase and then uses appropriate, what you call as cross cutting functions, we will talk about what the cross cutting functions are, cross cutting functions to develop the final system. So it all starts as the output of the system design process, where you have the requirements both the functional requirements and performance specs plus user expectations.

They are all part of the requirement analysis, where this was the output of the system design process, where we initially were designing the system. Then once it is done, what we do is, the design team, this team is the inter disciplinary plus multi-disciplinary team. So there will be multiple experts, there could be for example, in the UAV team there was a person whose was an expert in structures, there was a person who was expert in the design of the system and there was a person who was expert in what you call as controls.

So the inner disciplinary within the same discipline they could have multiple specializations also and there could be people who are across different disciplines. So, the design team is usually interdisciplinary and multi-disciplinary at the same time and they utilize the output from the system design process, which gave them the functional requirements, performance and user expectations.

They take all these inputs and then use cross cutting functions so the major cross cutting functions are in this regard what we call as cross cutting functions some of them major ones, one will be the data management, configuration management. So this is cross cutting functions, you manage the data and you manage the configuration. Data is necessary to, why is data necessary? It is to establish without ambiguity that performance measures are met.

So you want to establish without data ambiguity so the required data and also the configuration management because, this establish functional capability. You take cross cutting functions and along with cross cutting functions include technical assessments, you incorporate technical assessments. For why, why do you do that? To decide whether to make, whether to buy, whether to code or reuse the subsystems.

So if you say that I am going to make something, then you should know whether you have the capability to make. Say, I am going to buy something, then you have to decide whether you have the money to buy. If I am going to code something, then you should know whether you have the appropriate people with you to code this. Say if I am going to reuse a system, then you can say, then you need to know whether a system like this is available for reuse and can it be refurbished.

All those things need to be confirmed before getting into the realization. And then once you have that then you integrate the subsystems. The another aspect of this is also when you integrate the subsystem before integration, the products or components are verified through what we call as Technical Assessment Process popularly known as TAP. So before we integrate the sub systems, we verify them through the Technical Assessment Process to ensure why do we do this?

To ensure that they are consistent with the technical data package or here we are answering the question "the product or system is built right". That is what we are talking at this point or in a way this is also called as Consistency establishment. See you are establishing that the product is consistent. It is consistent with the technical data package or it fulfills what we call as the performance capabilities that were required. So this is a very important step because before you integrate you want to ensure that it is the consistency is established.

So once you establish consistency, once consistency is established or once you achieved consistency, what you do? The team validates the products against what we call as customer expectations. So this point of time you are trying to ensure that the right product is built. That's the second part. So because this slide is getting crowded we will move on to the next slide and we will try to continue there.

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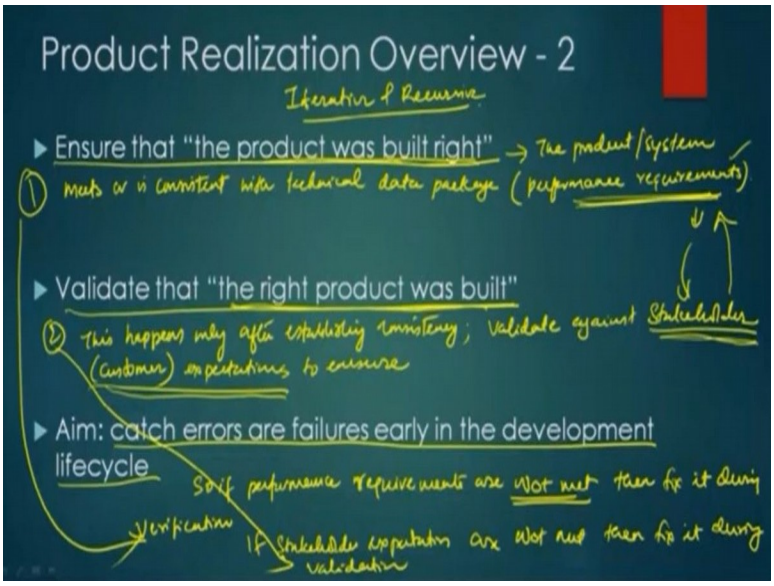

So, the first part is that ensure that "the product was built right". Product was built right means the product or the system meets or is consistent with technical data package or another way to say it as performance requirements. So you want to ensure that the product or system is consistent with technical data package or the performance requirements. It meets the performance requirements so that the product that is built is, you built the product right, and the product was built right. That is the most important aspect of it.

Then the second part as once we said validate that "the right product was built". This happens only after establishing consistency. The first thing is you have to ensure that the performance requirements are met. Once you established that the performance requirements are met then what you do is validate against stakeholder or another way to use stakeholder is customer expectations to ensure, to ensure what, ensure that the right product was built or the product that was, the first case is the product was built.

So this satisfy performance requirements. Then the second case is that right product was built which means it satisfies the stakeholder or customer expectations. Both are different. There is in many of times people will confuse between both but verification and validation are two different separate steps which are important as part of the product realization process. Why do we do this? What is the main reason? The main reason is to catch errors and failures early in the development lifecycle.

So if performance requirements are not met, then fix it during verification. So this is where this part happens. If stakeholder expectations are not met, then fix it during validation. So it happens at this point. So, this is why this process is also called, as remember I always used to mention this term Iterative and Recursive.

So, sometimes you find out that at the time you say, ok I met all the performance requirements and when you reach there you say that ok, I am not meeting one customer expectation because of a choice I made here so then you go back and revisit and then redo the stuff, so that you come up with something else that still miss a performance requirement, so that you can satisfy the customer expectations or stakeholder expectations. So this iterative and recursive process together ensures that the system works in the way it is supposed to work.

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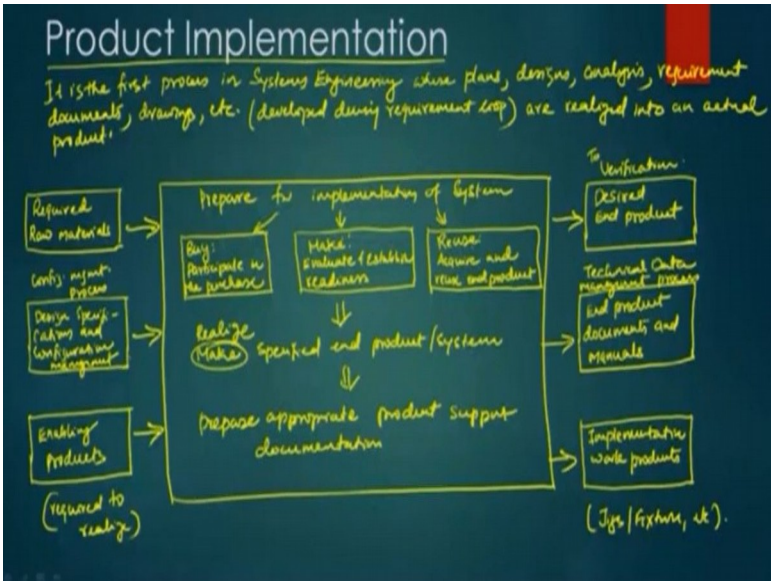

So we will now move in to the first step of the process, which is called as the Product Implementation. So product implementation, if you write about this the product implementation, it is the first process in systems engineering. This is a first process in Systems engineering where plans, designs, analysis, requirement documents, drawings etc. All these kind of weird things that were developed at the, so all these were developed during requirement loop.

This is the first process in systems engineering where plans, designs, analysis, requirement documents, drawings etc. are realized into an actual product. So this is why this step is very important and if you graphically look at it, if you look at the overview of the step, then we can draw it in a graphical format so for us for easily remembering. So the first one is we talk about is the required raw materials, then we also have what we call as the design specifications and configuration management.

This comes from the configuration Management process. Then we also have what we call us enabling products, we will talk about what each one of them, enabling products. These three becomes the input and then we have the process in which the first step is prepare for implementation of system in which you have three options. The first option being we will call it as buy. The second option we will call it as make and then the third option we will call it as reuse.

In the buy, if you are decide to buy then we participate in the purchase. So you participate in the purchase process. If you decide to make, evaluate and establish readiness. Readiness for doing what? Readiness for manufacturing. And reuse is acquire and reuse end product. So you look for where to get these things, where to get the end product and then find ways to reuse it. Once this is done, once these three things are done from there we move to the next step, which can be called as make specified end product or system.

So make a system or an end product that meets the specification or instead of using the make, let's say realize. Because it will Confused with the other make, so we will call it as realize as the phrase here. And then after that what we do is, we do prepare appropriate product support documentation, so these three inputs getting into the system. So obviously required raw materials, whatever is required, whether you are doing buy or make another things is part of this process.

Then you also require the design specification and configuration management document which will actually allow you to further design, which you are buying something what it is, you are making something what you are making. Then there is something called as enabling products.

These are required to realize. So, a simple word to think about this a tool bit is required to, like a drilling bit is required to drill holes in to a work piece or coolant is required to cool the work piece. So all these are kind of enabling products in that regard.

And from there the output happens, we can draw it in three parts again. The output, the first one is the desired end product, then we also have another output, which is the end product documents and manuals. And then the third one is, think about it as implementation work products. So this one will go to verification mostly, a desired end product will happens, so you have to verify that it meets the performance requirements and this also goes to the Technical data management process.

Three outputs that comes out of it and then implementation work products, So here is like you might come across something like Jigs, fixtures etc. So without these sometimes the manufacturing of the product is not feasible. So if you look at it you have inputs, the required raw materials, then the design specifications and configuration management and enabling products within which it goes into the what we call as the product implementation where you decide, whether you want to go, buy, make or reuse and then based on the options when you realize the specified end product.

And then prepare appropriate documentation and the documentation then will go to what we call as the end product, which is the technical data management process, the end product that is made will actually go to the verification process and the work products, implementation work products Jigs, fixture etc which are necessary for the whole thing actually gets transferred into the appropriate documentation section. So that, if you have to repeat this process we know what to do.

Hope that you understood the first step which is called as the product implementation step in this regard. We now will go into the second one which is called as the product integration.

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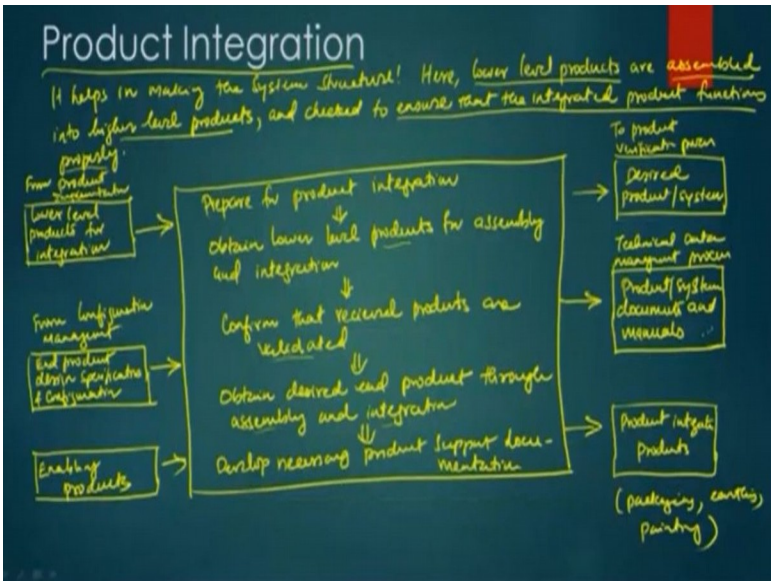

And product integration in this regard is the, it helps in making the system structure. What do we mean by it? Here lower level products are assembled, here we are doing the assembly process, you are going up again iterating and Recursion. Lower level products are assembled into higher level products and checked to ensure that the integrated product functions properly.

So if you look at it, we are integrating the lower level products are assembled, they are assembling them into higher level products and at the same time ensuring that the integrated product is functioning properly. So if you look at the diagram again or we look at the schematic of this, we can draw something like this similar so that it is easy to visualize and remember the one input will be lower level products for integration that will be one thing.

So where will it come from? From the first phase, which is the product transition, not transition, it actually would come from the product implementation. Then we talk about from configuration management we actually get second input which is the end product design specifications and configuration documents. All of them come from the configuration management and we also have the enabling products.

With this we create the system or the option where first thing what we do is we prepare for product integration. So in this step what we do is first thing is we obtain lower level products for assembling and integration then we do is confirm that received products are validated. Once you

confirm that, then you do is obtain desired end product through assembly and integration then develop necessary product support documentation.

So in this process first you prepare for the product integration then you obtain lower level products for assembly and integration then you validate that the received products, you confirm that the products or received products are the one that you are going to use to assemble to get the higher level products. They are validated, so your all sub-assemblies are validated. Then you obtain the desired end product through assembly and integration.

You conduct assembly and integration to obtain the end product and then you develop the necessary product support documentations. So these three becomes the input to the process and then there are also similarly there are three outputs the first output is the desired product or system. Then the other output is your product, system documents and manuals and then the third one is product integration products.

So whatever the enabling products that are required. So these are the three outputs that will come out of the system and you also know that this desired product or system that is developed it will move to product verification process, this will be the next one this will go to the technical data management process and this will be the end product. So sometimes you will probably have something like packaging, you have like earthing, you have like paintings some stuff like this which could all be in the product integration.

So these are like things that are required as part of this. So again if you look at the previous slide, which was the product implementation and the product integration what were we talked about. So the input from the product implementation has feedback into the product integration process and your sub-assemblies, you ensure that all these sub-assemblies are lower level products are validated products and then you assemble and integrate them to obtain the desired end product and then you also need the necessary documentation.

The documentation goes into the Technical data management process, the desired end product that was built and then goes into what we call as the product verification process and the final

things whatever is the packaging and another additional thing small, the enabling products that are required to ensure the assembly and integration of the products. Actually we keep the information of that because when you are actually manufacturing it in a large scale, these are required. Thank you.